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GB 1163679 A EP 0237184 A EP 0139387 A
US 4145607 A US 4128759 A

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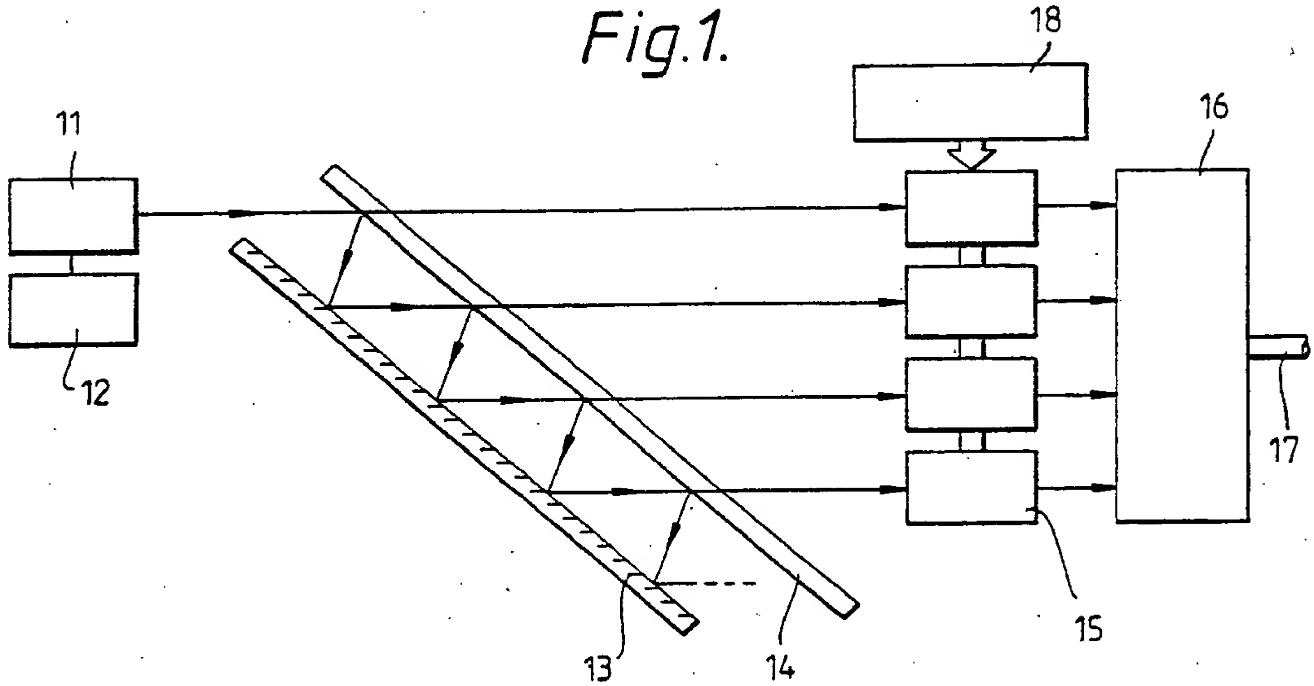
(54) **Optical transmitter**

(57) In an optical, e.g. soliton, pulse transmitter the pulse source, e.g. a solid state laser (11), is coupled to means for generating a series of time delayed pulses for each successive generated pulse. The delayed pulses which may be produced by multiple reflection of the laser signal between a pair of parallel plane mirrors (14, 15), are then combined (16) with the original pulse train. This generates a high bit rate pulse stream that may be modulated (15, 18) e.g. by omitting selected pulses, to transmit information.

Fig.1.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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Fig.1.

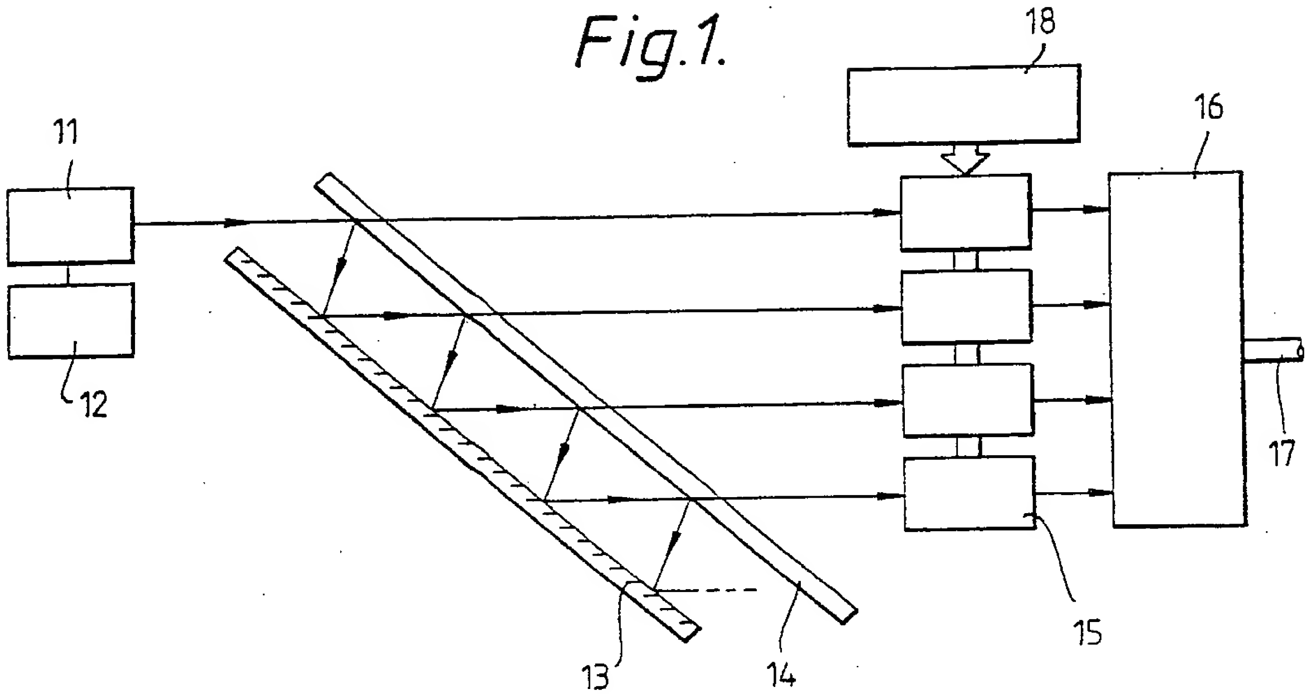


Fig.2a.

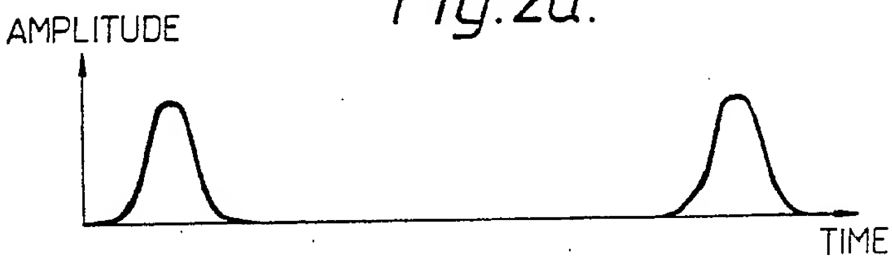


Fig.2b.

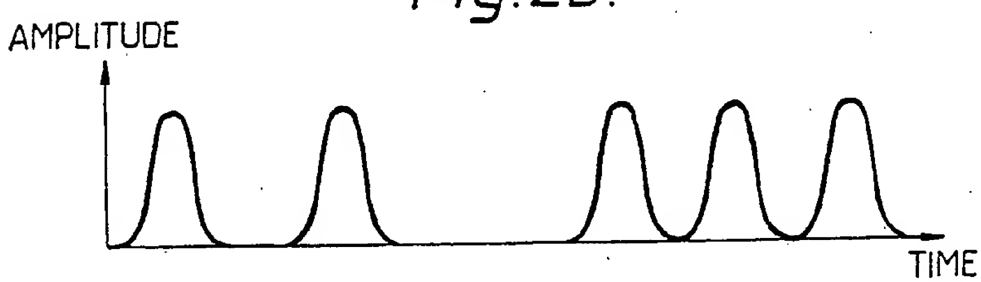


Fig.3.

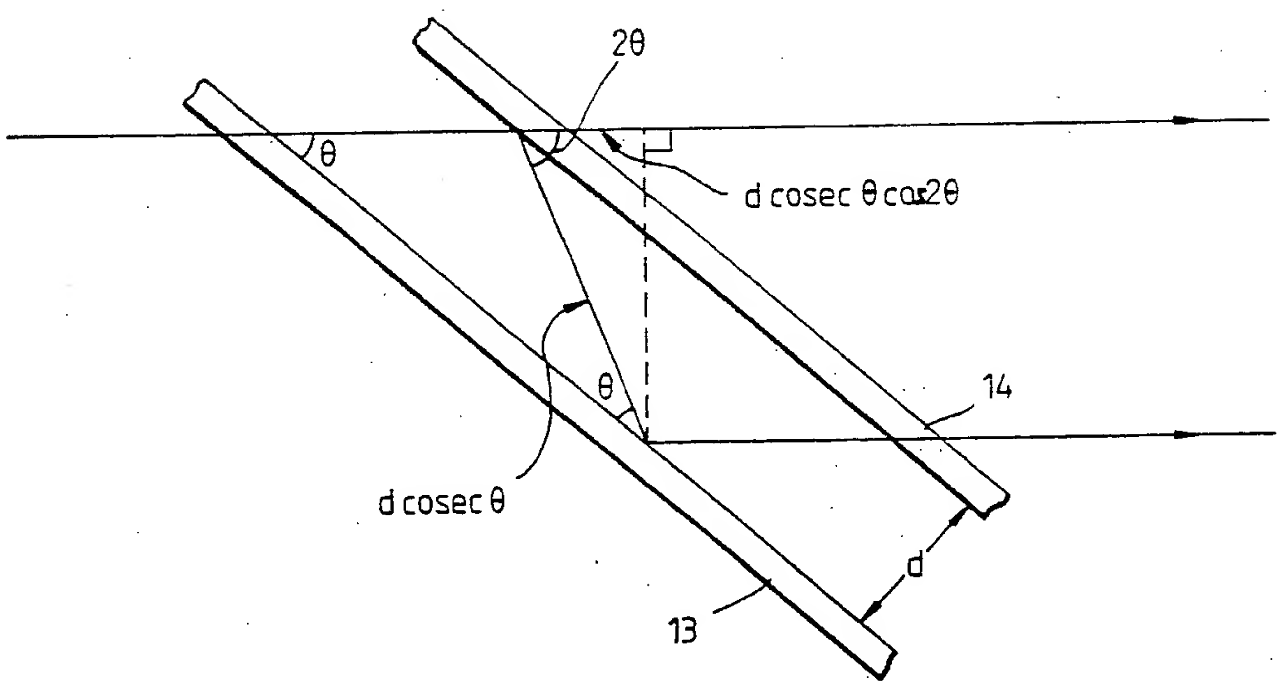


Fig.4.

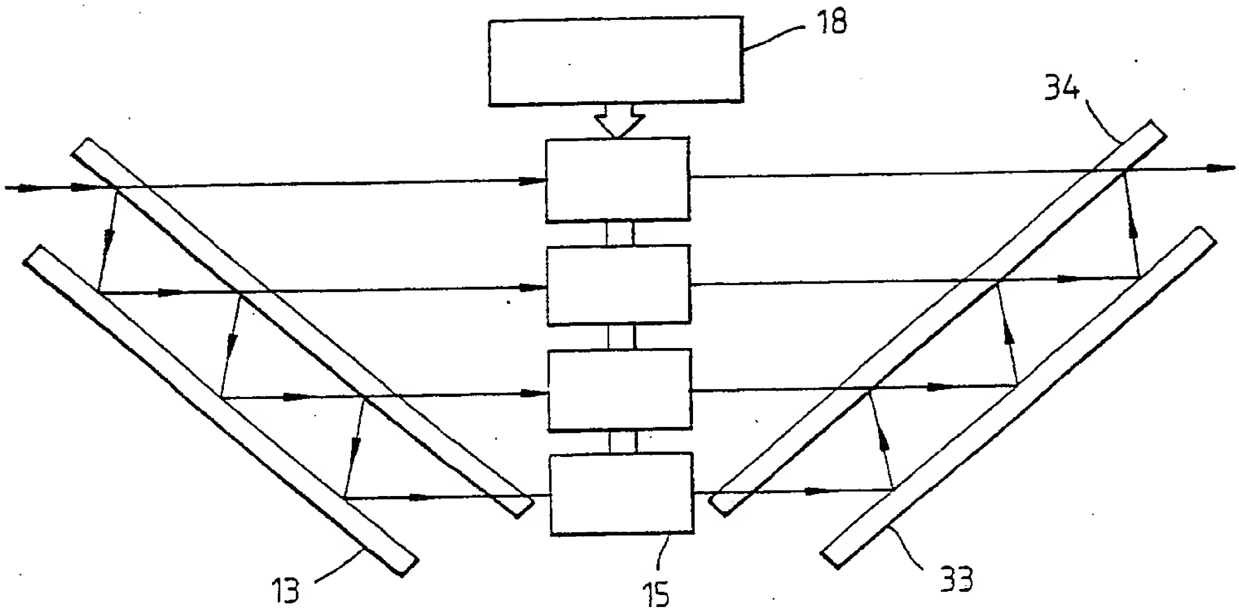
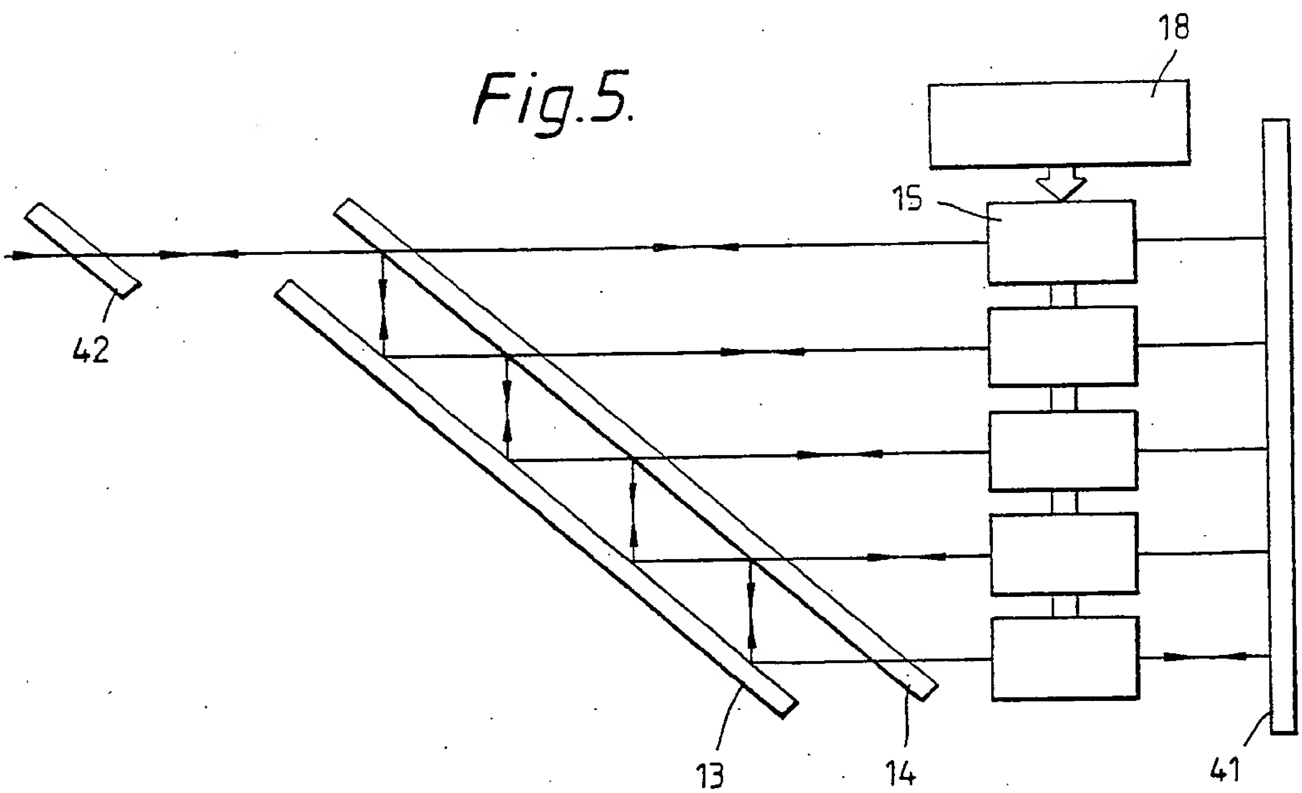


Fig.5.



Optical Transmitter

This invention relates to optical transmitters, e.g. for high bit-rate transmission, and to optical transmission systems employing such transmitters.

Fibre optic transmission systems are finding increasing application in the long haul transmission of speech and/or data signals. The wide bandwidth offered by an optical system represents a considerable advantage over conventional electrical signalling systems by providing a communications channel with a very large capacity.

A major problem associated with the long haul, e.g. transoceanic, transmissions of optical signals over a fibre optic path is that of degradation of the transmitted signal particularly as a result of dispersion by the fibre medium. Dispersion arises from velocity differences between the various frequency and/or modal components of the signal within the transmission medium and results in broadening of the component pulses of a transmitted signal. This effect limits the distance over which signals may be transmitted before regeneration becomes necessary. The problem can be somewhat reduced by an appropriate choice of transmission wavelength. Thus, it has been found that, for a silica optical fibre, there is a wavelength

at which the dispersion has a minimum (non-zero) value. Transmission of signals at or near this wavelength results in some improvement but does not obviate the need for regeneration. It will be appreciate that in a conventional optical transmission system, the regenerators are complex and costly devices which represent a significant proportion of the entire system cost. The regenerator must perform a number of function additional to signal amplification and including pulse reshaping, pulse retiming and error checking. These signal processing functions require that the received optical signal is converted to a corresponding electrical signal which is then processed before conversion back to an optical signal for retransmission. It will be appreciate that, with such a system, the operating bit rate and data format are an integral part of the system design and that the regeneration must conform to that design. In addition to the problem of the cost of the regenerators, there is the additional constraint that the system may not be upgraded, e.g. to operate at a higher bit rate, without modification or replacement of the regenerators. For a land-based system this is a costly operation, whilst for a submarine system recovery of the regenerators is generally impractical.

A recent development which addresses these problems is the generation of very short duration pulses, typically of 1 picosecond or less. These short duration pulses may be soliton pulses. A soliton is a solitary wave or pulse that propagates over long distances with substantially no dispersion. Such a technique is described in our co-pending application No. 90 01571.0 (R.E. Epworth 48). In this system the solitons are amplified at regular intervals by broadband optical amplifiers, there being no necessity for pulse reshaping or pulse retiming.

A limiting factor in this soliton transmission is the rate at which solitons can be generated. The pulses must have very closely defined amplitude and phase characteristics to ensure soliton purity. Current methods of soliton generation are capable of producing high amplitude pulses of the appropriate width, but at a relatively low repetition rate. This limits the rate at which information may be transmitted. Attempts to increase the rate of pulse generation have not proved successful as it has been found that the pulse format then departs significantly from the pulse soliton shape.

An object of the invention us to minimise or to overcome this disadvantage.

A further object of the invention is to provide an optical transmitter capable of generating pulses at a high repetition rate.

According to one aspect of the invention there is provided an optical transmitter adapted to generate a stream of optical pulses, the transmitter including means for generating a sequence of pulses, there being a significant interval between successive pulses of the sequence, means for deriving from said pulses further, time delayed similar pulses, and means for mixing the time delayed pulses with the pulse sequence whereby to insert the time delayed pulses into the intervals in that pulse sequence.

According to another aspect of the invention there is provided a method of coding information to be transmitted via an optical channel, the method including generating a sequence of optical pulses there being a time interval between successive pulses of the sequence, means for generating for each pulse of the sequence one

or more time delayed similar pulses, means for mixing the time delayed pulse with the pulse sequence whereby to provide a relatively high frequency pulse sequence, and means, responsive to an input information signal, for suppressing or modulating selected pulses of the high frequency sequence whereby to form a coded sequence corresponding to the information signal.

Advantageously the generated pulses are soliton pulses.

Embodiments of the invention will now be described with reference to the accompanying drawings in which:-

Fig. 1 is a schematic diagram of a high repetition rate optical pulse transmitter device,

Fig. 2 illustrates the generated and output pulse sequences of the transmitter device of Fig. 1;

Fig. 3 illustrates the geometric optical paths of the device of Fig. 1;

Fig. 4 is a schematic diagram of an alternative transmitter device;

and Fig. 5 shows a further transmitter device.

Referring to Fig. 1, the transmitter device includes a light source 11, e.g. a solid state laser operating in the infra-red region of the spectrum, and an associated drive circuit 12 whereby the laser emits soliton pulses at regular intervals. The laser output is directed to a pulse multiplier arrangement comprising first (13) and second (14) plane parallel mirrors. One mirror 13 is fully reflecting whilst the other mirror 14 is half silvered so as to be partially reflecting. The laser beam undergoes a series of reflections, each reflection including a further time delay corresponding to the optical path length. Thus, the pulse multiplier

produces a series of parallel output signals each of which comprises a respectively delayed pulse of similar format to that of the input laser pulse, the precise time delay between successive pulses being determined by the spacing between the two mirrors 13 and 14 and by their angle of incidence to the laser output.

It will be appreciated that there will be an optical power loss of the signal at each successive reflector. This effected can be compensated either by a progressive reduction of the silvering of the second mirror 14 in the direction towards the higher order reflections, or by introducing differential attenuation to the output signals from the pulse multiplier e.,g. by the use of a wedge-shaped neutral density filter (not shown).

Each output signal from the multiplier passes via a respective modulator 15 to a passive combiner 16 whereby the individual signals are combined into a single pulse stream for transmission via an optical fibre path 17 to a remote receiver (not shown). The combiner 16 may comprise a lens.

The modulators 15 may modulate the pulses in both phase and amplitude. In a particularly advantageous arrangement the successive pulses of the combined pulse stream are so modulated as to be in mutual phase quadrature. This minimises interaction between adjacent pulses of the stream.

The modulators are coupled to a modulation circuit 18 whereby each modulator 15 is controlled so as to suppress selected pulses in response to an input information signal to the modulation circuit. In this way the information is transmitted over the fibre optic path as a corresponding coded pulse sequence. The pulse

stream of the transmitter of Fig. 1 are illustrated in Figs. 2a and 2b which show respectively the lower frequency laser pulse output and the higher frequency modulated transmitted signal.

Referring now to Fig. 3, the optical path between the two mirror surfaces is illustrated for the direct (unreflected) beam and a single reflection. The mirrors 13, 14 are disposed at an angle θ to the incident light beam.

The path length of the reflected light beam between its two points of reflection at the mirror surface is equal to d.cosec θ where d is the perpendicular distance between the mirror surfaces. After the second reflection of this reflected beam the path length between this beam and the direct or unreflected beam is given by the expression:-

$$
\begin{aligned}
& d.\operatorname{cosec}\theta - d \operatorname{cosec}\theta \cos 2\theta \\
&= d.\operatorname{cosec}\theta \, (1 - \cos 2\theta) \\
&= 2\, d.\sin\theta .
\end{aligned}
$$

Similarly, each subsequent reflection introduces a further path length of $2\,d \sin\theta$. Typically the mirror assembly is disposed at an angle of 45° or $\pi/4$ to the incident beam, thus introducing a path difference of $\sqrt{2}d$ at each reflection stage.

In a typical system, pulses of about 1 p.sec duration may be generated at a rate of 10 Gbit/sec. This corresponds to a time spacing of about 100 p.sec between successive pulses. Conveniently nine pulses may be inserted into this time gap to give a new pulse rate of 100 Gbit.sec. I.e. the required time delay introduced by each reflection stage is 10 p.sec. This corresponds to a spacing d between the mirrors of about

2 mm. The precise delay required to ensure even spacing of the pulses in the pulse stream may be determined by adjustment of the spacing between the mirrors.

Fig. 4 illustrates a modification of the transmitter of Fig. 1. In this arrangement the higher frequency pulse stream is generated from the laser input by a pair of mirrors 13, 14 as described above. However, the beam combining function is provided by a further pair of mirrors 33, 34, one of which (33) is fully silvered and the other of which (34) is partially silvered.

A further modification of the transmitter of Fig. 1, is illustrated in Fig. 5. In this arrangement a plane fully silvered mirror 41 is employed to provide a folded optical path for the pulse signals. The input laser signal is fed to the pair of mirrors 13, 14 via a beam splitter 42 which combines the laser pulses with the modulated pulse signals reflected via the mirror 41 to provide the composite higher frequency output signal for transmission.

Advantageously the various transmitter arrangement described above may be provided in the form of an integrated system associated with a planar waveguide.

It will be appreciated that although the above technique has been described with reference to the generation of soliton pulses, it is not limited to that application but may also be employed for the processing of a variety of short duration pulse formats.

CLAIMS

1. An optical transmitter adapted to generate a stream of optical pulses, the transmitter including means for generating a sequence of pulses, there being a significant interval between successive pulses of the sequence, and means for deriving from said pulses further, time delayed similar pulses, and means for mixing the time delayed pulses with the pulse sequence whereby to insert the time delayed pulses into the intervals in that pulse sequence.

2. A transmitter as claimed in claim 1, wherein saidf pulses are soliton pulses.

3. A transmitter as claimed in claim 1 or 2, wherein said time delayed pulses are phase modulated.

4. A transmitter as claimed in claim 3, wherein adjacent time delayed pulses are in phase quadrature.

5. A transmitter as claimed in claim 1 or 2, wherein the time delayed pulses are generated via a pair of parallel mirrors between which the sequence of pulses undergoes a series of reflections.

6. An optical transmitter substantially as described herein with reference to and as shown in Fig. 1, 4 or 5 together with Figs. 2 and 3 of the accompanying drawings.

7. A method of coding information to be transmitted via an optical channel, the method including generating a sequence of optical pulses there being a significant time interval between successive pulses of the sequence, means for generating from each pulse of the sequence one or more time delayed similar pulses, means for mixing the time delayed pulse with the pulse sequence whereby to provide a relatively high frequency pulse sequence, and means, responsive to an input information signal, for suppressing or modulating selected pulses of the high frequency sequence whereby

to form a coded sequence corresponding to the information signal.

8. A method of coding information substantially as described herein with reference to and as shown in the accompanying drawings.

9. An optical transmission system incorporating one or more transmitters as claimed in any one of claims 1 to 6.

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